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# Effects of silvicultural activity on ecological processes in floodplain forests of the southern United States: a review of existing reports

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## Abstract

Activities associated with timber harvesting have occurred within floodplain forests in the southern United States for nearly two hundred years. However, it is only in the last ten years that any information has become available about the effects of harvesting on the ecological functions of this valuable resource. Hydrology is the driving influence behind all ecological processes in floodplains, and timber harvesting alone usually has little long-term effect on hydroperiod. However, logging roads, built in association with harvest sites, can sometimes alter hydroperiod to the extent that vegetation productivity is raised or lowered. There is no evidence that harvesting followed by natural regeneration represents a threat to ground or surface water quality on flood plain sites, as long as "best management practices" are followed. Harvested floodplains may increase or have little effect on decomposition rates of surface organic matter. The nature of the effect seems to be controlled by site wetness. Data from recently harvested sites (i.e. within the last ten years) suggest that vegetation productivity is maintained at levels similar to those observed prior to harvests. During the early stages of stand development, tree species composition is heavily influenced by harvest method. Similarly, amphibian populations (monitored as bioindicators of ecosystem recovery) seem to rebound rapidly following harvests, although species composition may be different from that of unharvested stands.

Keywords: Wetland forests; Harvests; Functions

## 1. Introduction

Riverine systems represent the largest area of forested wetlands in the United States although estimates of their extent in the southern United States vary from 6 to 13 million ha (Sharitz and Mitsch, 1993). Riverine forests are important functionally because of a high degree of hydrologic interconnec-tivity within the landscape. Thus, they have great potential for influencing the chemistry and biology of aquatic systems (Brinson, 1993). As a result, forest management activities that alter the biogeochemical transformations that occur within riparian forests can influence much larger portions of the landscape.

Floodplain forests typically are occupied by a

mosaic of vegetation communities that are defined by hydroperiod (Shelford, 1954; Hodges, 1997). Areas such as deepwater swamps with long hydroperiods (that is, prolonged flooding) may be dominated by water tupelo (*Nyssa aquatica*) and baldcypress (*Taxodium distichum*) while the wetter portions of active floodplains could be occupied by sweetbay (*Magnolia virginiana*), overcup oak (*Quercus lyrata*), red maple (*Acer rubrum*), water hickory (*Carya aquatica*), and laurel oak (*Quercus hemisphaerica*). Moderately well-drained areas may support sweetgum (*Liquidambar styraciflua*) and water oak while cherrybark oak (*Quercus pagoda*) and black gum (*Nyssa sylvatica*) often occur on better drained sites (Sharitz and Mitsch, 1993; Hodges, 1997). While floodplain forests are clearly dominated by deciduous species, the occurrence of slash pine (*Pinue elliottii*), spruce pine (*Pinue glabra*) or loblolly pine (*Pinue taeda*) is also common, depending upon hydroperiod and past management.

Annual litterfall ranges between 3 and $7 \, tha^{-1}$, and total aboveground biomass production ranges between 7 and $20 \, tha^{-1}$ among types of riverine forests in the southeastern United States (Brinson, 1990; Conner, 1994). The high values of litter and biomass production indicate that some floodplain forests are among the most productive forests of the temperate zone (Bray and Gorham, 1964; Rodin and Bazilevich, 1967). Brinson (1993) reviewed the literature on net primary production (NPP) and found no latitudinal patterns of NPP in floodplain systems. He concluded that intrasystem hydrology dominated over climatic variation as the controlling factor behind floodplain NPP.

In terms of their biogeochemistry, forested floodplains of the southeastern United States fall into two categories: alluvial, or redwater; and black water (Wharton, 1978; Walbridge and Lockaby, 1994). Alluvial riverine systems are those which arise outside of the coastal plain, within watersheds which lie in physiographic units with clayey soils that typically have relatively high concentrations of inorganic ions. Watersheds of blackwater systems lie within the coastal plain sediments of predominantly sandy soil. Blackwater rivers and streams are usually low in inorganic nutrients and may be colored by organic constituents. Consequently, alluvial systems tend to be eutrophic while those of blackwater systems may

be more oligotrophic. In particular, blackwater systems may be very low in phosphorus (P) (Lockaby et al., 1994).

## 2. Effects of past land-use on present floodplain systems

The current condition of almost all floodplain forests in the southeastern United States reflects the integration of natural factors plus the influence of past human activities (Wharton, 1978; Kellison and Young, 1997). The nature and intensity of previous activities varied widely, sometimes including clearing for agriculture. Historical patterns of the most prevalent land use activities practiced in a given area depended to a large degree on when an area was settled (Williams, 1989; Kellison and Young, 1997). As an example, the spatial pattern of species occurrence in some floodplain forests of the Atlantic coastal plain reflects altered hydroperiods that result from 19th and early 20th century agricultural ditching for drainage or diking for flooded rice culture (Lockaby et al., 1997b; Kellison and Young, 1997; Stanturf et al., 1995).

Floodplains that were less accessible or inherently wetter may not have been farmed but were likely subjected to logging. In many cases, exploitative logging removed only larger trees of valuable species such as baldcypress, oak spp., or pine spp. Logs were removed using animals, spur railroads, and within the wettest areas, pull boats (Walker, 1991; Williams, 1989). Influences of selective logging on the present-day structure and composition of floodplain forests are more subtle than those caused by agricultural drainage and clearing, therefore, it is difficult to assess the degree to which lasting effects may have occurred. Except for pull-boat logging and its associated canal systems, selective logging likely caused little alteration in hydroperiod and we theorize that most changes in site quality were short-term and the greatest impact was the alteration of the species composition by removal of seed sources.

## 3. Silvicultural systems presently used

Historical use of selection/high-grade logging in floodplain forests has evolved to an almost complete

reliance, at the present time, on clearcut systems coupled with natural regeneration (Walbridge and Lockaby, 1994; Kellison and Young, 1997; Meadows and Stanturf, 1997; Putnam et al., 1960). However, interest in partial cutting is increasing (Meadows and Stanturf, 1997). Clearcut systems may utilize either manual or mechanized methods for felling, the latter necessitating an additional entry by large equipment. The majority of log removal systems are ground-based, skidder operations with tire widths sometimes widened to reduce ground-pressure and soil disturbance caused by machinery (Aust et al., 1997; Stokes and Schilling, 1997). A small percentage of harvesting operations utilize helicopters to remove logs. The natural regeneration methods normally used require no site preparation so that site disturbance is confined only to the harvest and log removal phases, from machinery traffic and road construction (Rummer et al., 1997; Stokes and Schilling, 1997).

## 4. Responses to silvicultural disturbance

### 4.1. Hydrology

Harvests alone may cause only subtle, short-term changes in hydrology of floodplain forests. The most common hydrologic change is elevation of soil water tables (Aust and Lea, 1992; Perison et al., 1997; Lockaby et al., 1997b), also seen on many upland sites owing to a reduction in evapotranspiration after temporary removal of the transpiring vegetative surface. Evaporative losses from clearcuts are influenced by higher soil temperatures from increased solar radiation at the soil surface. Elevation in average soil temperature on floodplains dominated by medium-colored, mineral soils has been minimal (e.g. 2–4°C higher within cut areas (Aust and Lea, 1991; Messina et al., 1997)).

The magnitude of treatment differences in soil temperature, however, may be masked by diurnal or seasonal averages. Comparisons of temperature between uncut controls and clearcuts during mid-summer on the Flint River floodplain (a medium-colored, mineral soil) revealed the clear cut was 11°C higher at noon, and the control was 2°C lower at midnight. These diurnal differences between closed-

canopy and open areas have been widely known for many years (Kittredge, 1948). Soil temperature differentials at noon during mid-summer may be even greater on floodplains dominated by dark, Histosols (e.g. +20°C in clearcuts (Lockaby et al. (1997a)).

The persistence of high water tables into the growing season following canopy removal is routinely reported as "water table rise" on floodplains where mineral soils dominate. The extent of the water table rise is most pronounced in the short interval prior to re-establishment of vegetative cover: generally no more than one or two growing seasons. The magnitude of the effect may be small, for example only a 14 cm rise on clearcut plots of a floodplain dominated by mineral soils was found by Lockaby et al. (1997b). An unusual post-harvest water table response was documented in a floodplain forest on dark-colored, organic soils (Lockaby et al., 1994). In this instance, depth to water tables increased (i.e. water table was lowered) until vegetation canopies re-established in the second year after harvest. This effect may have been caused by stimulation of evaporation from the dark soils: a theory based on the higher soil temperatures within harvest areas. Thus, water table responses within harvested areas are likely to be partly a function of the color and composition of the soil matrix and the corresponding temperature increases.

Compared to the relatively minor effects of tree removal alone, floodplain forest hydrology may be greatly affected by the design of logging roads. Culverts, ditches, and roads designed as elevated berms may alter sheetflow velocity (Rummer et al., 1997) and direction (Lockaby et al., 1997b). If sheetflow is altered to a significant degree, vegetation productivity (Young et al., 1995) and nutrient transformation (Lockaby et al., 1997b) and other floodplain functions may also be altered. A report of altered radial growth in baldcypress following establishment of a logging road which changed sheet flow depth suggests that such changes may be long-term in nature (Young et al., 1995).

## 5. Biogeochemistry

Several studies have examined the effect of harvest disturbances on rates and magnitudes of nutrient

cycling within floodplain forests as well as on geochemical input–output relationships. Although harvest studies in upland forests have sometimes demonstrated a reduction in decomposition rates (Will et al., 1983), similar investigations in wetlands have generally shown accelerations (Mader et al., 1988; Lockaby et al., 1997a). In floodplains of low-order streams in Alabama, increased mass loss within harvested zones was slow to occur as a result of the inherent wetness of that particular site (Lockaby et al., 1997a). The divergent responses between upland and floodplain systems probably reflect the greater tendency in the former for soil moisture to become limiting to microbes following canopy removal and subsequent elevation of soil temperatures.

Temporal patterns of nitrogen (N) and P immobilization versus mineralization in decomposing litter appear to be particularly sensitive to changes in soil microclimate brought about by harvest disturbance. In Figs. 1–3 (Griffin et al., 1993), P immobilization/mineralization patterns become more stable as the severity of harvest disturbance increases in the order control < helicopter < skidder. It is useful to compare treatment effects within a floodplain on the basis of these patterns, as they reflect integration of microbial activity and nutrient availability. Alteration of temporal patterns will affect the timing and magnitude of nutrient availability in some floodplain systems, thereby influencing species composition of
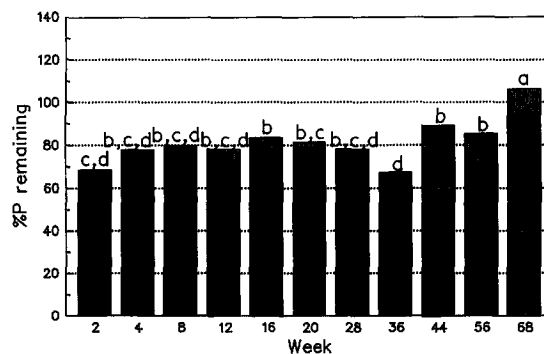


Fig. 2. Phosphorus immobilization versus mineralization pattern in litterbags on plots harvested by helicopter. Percentage P remaining less than 100% indicates mineralization; greater than 100% indicates immobilization. Weeks with the same letter are not statistically different at the P = 0.05 level (After Griffin et al. (1993)).

replacement vegetation as well as geochemical source and sink relationships.

The capacity of floodplain forests to serve as sinks, sources, or transformation zones for nutrients has been clearly documented (Brinson, 1993). Specific relationships depend upon landscape position, the magnitude of elemental inputs, and the time since disturbance. Recently, there has been concern that silvicultural activity such as harvesting and site preparation might stimulate source behavior for a number of non-point source pollutants (e.g. sediment
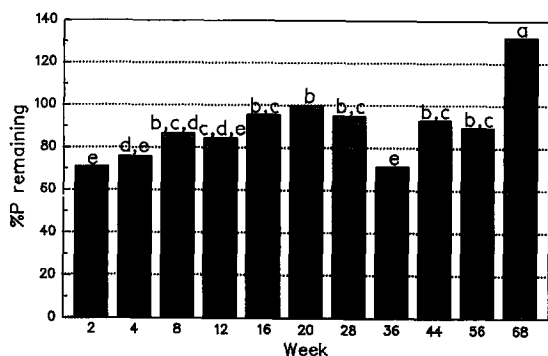


Fig. 1. Phosphorus immobilization versus mineralization pattern in litterbags on the undisturbed portion of the floodplain, Little Escambia River, Alabama. Percentage P remaining less than 100% indicates mineralization; greater than 100% indicates immobilization. Weeks with the same letter are not statistically different at the P = 0.05 level (After Griffin et al. (1993)).
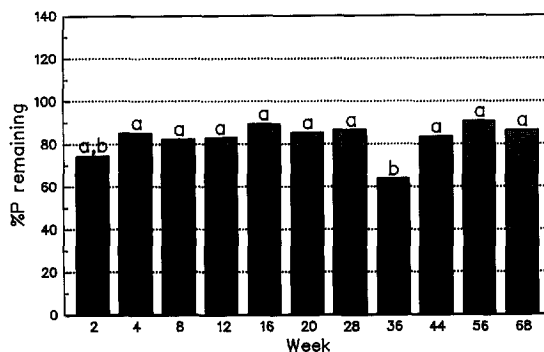


Fig. 3. Phosphorous immobilization versus mineralization pattern in litterbags on plots harvested by conventional skidders. Percentage P remaining less than 100% indicates mineralization; greater than 100% indicates immobilization. Weeks with the same letter are not statistically different at the P = 0.05 level. (After Griffin et al. (1993)).

and nitrate). However, the magnitude of source activity has been shown generally to be small and the longevity of any effects to be short-term (Shepard, 1994; Lockaby et al., 1994; Messina et al., 1997). There are strong indications that following revegetation, sediment deposition is stimulated by the rougher surface of harvested sites and the associated loss of energy in sheetflow (Aust et al., 1997; Scott et al., 1990; Perison et al., 1997).

The degree to which silvicultural disturbance alters the capacity of a floodplain forest to transform nutrients (Elder, 1985) is less certain. Transformation processes are more subtle chemically and biologically than the occurrence of non-point source pollution. Sediment and chemical exchange between sheetflow and floodplain surface soils were studied in the first year following harvests in Georgia (Lockaby et al., 1997b). Few differences were found in sheetflow chemistry between partial harvests and unharvested areas. Both areas detained basic cations and released nitrate. The data suggested that total organic carbon export was increased from partially harvested areas, probably as a result of the large amounts of coarse woody debris there.

## 6. Vegetation composition and productivity

Clear assessments of the degree to which different silvicultural operations (eg. skidder versus helicopter removals) may affect the composition, and productivity of woody species are hampered by the brief timespans (one–two years) of most studies to date (Lloyd, 1995; Messina et al., 1997). An exception is the harvest response study of Aust et al. (1997) which compared woody vegetation characteristics following aerial-and ground-based log removal in the Mobile River Delta of south Alabama. Although post-harvest species composition differed between the two log removal systems, total above-ground biomass and stem densities were similar after seven years. However, none of the harvest impact studies under way are old enough to permit direct comparison of NPP between harvested and control plots.

Increased soil bulk density and reduced saturated hydraulic conductivity have been reported on some sites (Aust and Lea, 1992; Lockaby et al., 1997b; Messina et al., 1997), and it is possible that inherent site quality may be changing owing to ground-based operations. Long-term productivity declines following ground-based harvests have been reported on upland sites in the southern United States. Haywood and Tiarks (1995) argue that future productivity assessments of aerial and ground-based systems studied recently (Aust and Lea, 1991; Aust et al., 1997; Perison et al., 1997; Lockaby et al., 1994; Lockaby et al., 1997b; Messina et al., 1997) are warranted as those stands mature.

Evidently the mode of log removal (i.e. aerial or ground-based) can make a major difference in terms of species composition in the first year following harvests (Walbridge and Lockaby, 1994). In general, species which reproduce primarily from seed are favored by ground-based operations while those that regenerate by sprouting are favored by aerial harvesting. The divergent responses are probably due to a greater tendency for damage to occur to roots and stumps with ground-based equipment. Whether stands continue to reflect different species composition as they mature is uncertain.

There also appears to be potential for manipulation of oak composition in floodplain forests through the use of partial cuts which may precede a clearcut by a variable number of years (Barry and Nix, 1992). Results from a regeneration study by Messina et al. (1997) indicated the reliance of early post-harvest species composition on stand composition prior to harvest. Although there is strong evidence that the type of log-removal system and the occurrence of intermediate operations both influence species composition, much uncertainty remains in mixed-species uneven-aged floodplain forests concerning the best methods to use for guiding composition to a desired outcome (Meadows and Stanturf, 1997). Foresters have known for some time that adequate regeneration of high-value oak species requires both a sufficient number of well-established oaks, advance reproduction and stump sprouts from severed oak stems. Recent revisions to a technique developed by Johnson (1980) to predict regeneration potential of natural stands reduces the contribution of small (less than 30 cm tall) advance oak seedlings but increases the weight given to ash seedlings greater than 30 cm tall (Johnson and Deen, 1993; Hart et al., 1995). However, the silvical requirements of other species for adequate regeneration are not as well known, and

the maintenance of pre-harvest diversity after cuttings is difficult to manage precisely.

## 7. Amphibian population dynamics

Amphibian population surveys commonly are used as an index of faunal habitat quality, as well as of general ecosystem integrity (Vitt et al., 1990). Amphibians are particularly sensitive to changes in habitat (Pechmann et al., 1989; Blaustein and Wake, 1990; Hayes and Jennings, 1990) and have small home ranges (Corn and Bury, 1989), and many species occupy terrestrial–aquatic ecotones (Wyman, 1990). Thus, amphibians are well suited to evaluations of floodplain disturbance.

In a minor bottom floodplain, Clawson et al. (1997) found that density was affected only marginally but that diversity declined sharply immediately after helicopter harvests. However, diversity recovered by six months after harvests, presumably as vegetative cover was re-established and surface soil temperatures began to return to pre-harvest ranges. Although the number of species recovered, shifts in species composition persisted during the two-year study. Phelps and Lancia (1992) and Perison et al. (1997), working in the coastal plain of South Carolina reported greater diversity in clearcut areas although no statistical differences existed between clearcuts and controls. As in the case of vegetative responses, the time required for re-establishment of pre-harvest amphibian populations (or the degree to which re-establishment may occur at all) is unknown.

## 8. Conclusions

Existing studies indicate that clearcuts with natural regeneration are generally compatible with major functions of floodplain forests. We summarize the current state of knowledge regarding the influences of clearcutting with natural regeneration on functions and values of forested floodplains in the southeastern United States in Table 1. This summary applies only where best management practices are used. This regeneration system is particularly innocuous if logs are removed aerially. Based on our understanding of

Table 1
Magnitude and duration of influences of clearcut/natural regeneration systems on selected functions and values of floodplain forests in the southern US

| Function/value | Magnitude | Duration |
| --- | --- | --- |
| Vegetation productivity | ? | ? |
| Vegetation species | Moderate | ? |
| Nutrient circulation | Moderate | ? [a] |
| Nutrient transformation | Small | Moderate |
| Water quality | Small | Brief |
| Hydrology – harvests | Small | Brief |
| Hydrology – roads | Moderate | Long-term |
| Amphibian populations | Major | ? |

[a] Dependent on trends in species composition and productivity.

both historical and current land management practices, we believe there is less potential to induce long-term changes when management does not alter hydroperiod or only marginally influences soil properties such as hydraulic conductivity.

There is a need, however, to clarify potential influences of logging roads on hydroperiod and, subsequently, on vegetation productivity and biogeochemical transformation functions. We also need to broaden our understanding of the ecological processes that affect biogeochemistry of floodplain forests and the effect of land management on these important functions. Finally, reassessment of vegetation productivity and faunal population dynamics on floodplains which were harvested 10–20 years ago are badly needed in order to assess the resilience of these factors.

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